

**Results From Testing And Analysis Of Solar Cells
Flown on LDEF**

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Results from Testing and Analysis of Solar Cells Flown on LDEF

This presentation provides a brief discussion of the solar cell experiments flown on LDEF. The information presented is a collation of results published by the various experimenters. This process of collation and documentation is an ongoing Systems SIG effort. No testing of solar cells has occurred at Boeing.

OUTLINE

- **Overview of solar cells flown**
- **Description of the various cell experiments and results to date**
- **Summary of findings**

SOLAR CELLS FLOWN FOR VARIETY OF PURPOSES

- **Four arrays actively charged a NiCd battery**
- **Cells actively monitored for first 325 days of mission**
- **Cells were functioning components of active experiments**
- **Cells, coverglasses, adhesives, and array materials passively exposed**
- **Variety of LEO exposures**
 - **Leading edge**
 - **Trailing edge**
 - **Space end**

Solar Cells Flown for a Variety of Reasons

There were nine LDEF experiments that possessed solar cells, solar cell components, and/or solar array materials. The complexity of experiments ranged from active on-orbit monitoring of solar cells (Experiment S0014) to recharging a nickel-cadmium battery used to power a heat pipe experiment (Experiment S1001) to passive exposure. The vast majority of solar cells were silicon based but two experiments flew GaAs solar cells (Experiments S0014 and M0003-4).

Table of Experiments Possessing Solar Cells

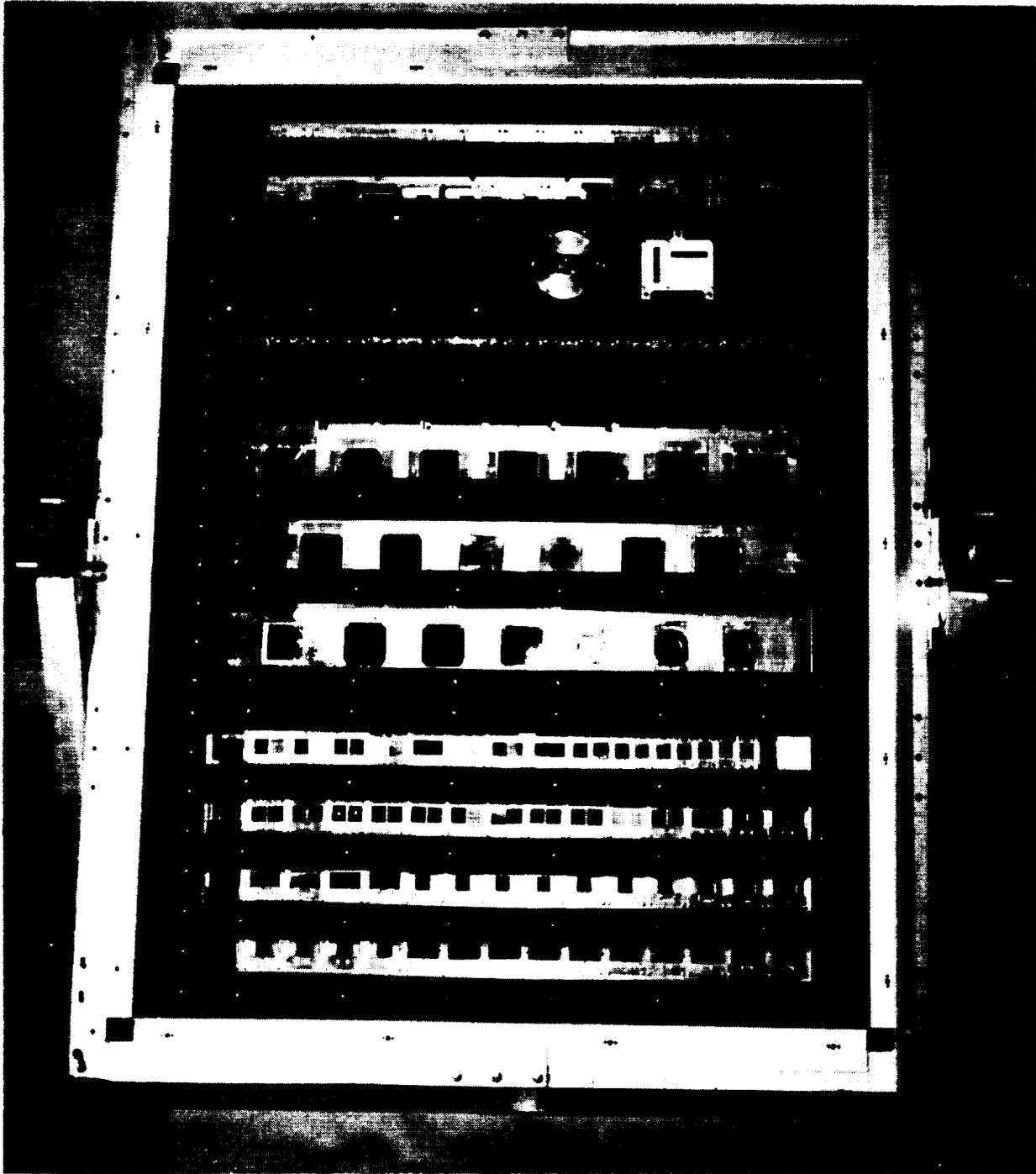
This chart shows the various solar cell experiments that were flown on LDEF. Information provided on this chart includes the current principal investigator, type and number of cells flown, name of experiment and location of experiment on LDEF. The degrees from ram take into account LDEF's constant 8 degree offset to ram. This presentation does not describe the specific types of cells and solar cell/array materials flown on LDEF. These details can be obtained from the individual experimenter or the LDEF Project Office. The Systems SIG has given the development of a solar cell database high priority but this activity is dependent upon 1992 funding.

List of LDEF Experiments Possessing Solar Cells

Principal Investigator	Type of Cells	Number of Cells	Experiment	Experiment Location
NASA LeRC - D. Brinker	Si & GaAs	155	S0014 - Advanced Photovoltaic Experiment	Tray E9 (8° from ram)
NASA MSFC - A. Whitaker	Si	4 modules & 5 cells	A0171 - Solar Array Materials Passive LDEF Experiment	Tray A8 (38° from ram)
NASA LeRC - D. Brinker	Si	20	A0171 - Solar Array Materials Passive LDEF Experiment	Tray A8 (38° from ram)
JPL - P. Stella	Si	30	A0171 - Solar Array Materials Passive LDEF Experiment	Tray A8 (38° from ram)
NASA GSFC - E. Gaddy	Si	45	A0171 - Solar Array Materials Passive LDEF Experiment	Tray A8 (38° from ram)
Wright Pat AFB - T. Trumble	Si & GaAs	70	M0003-4 - Advanced Solar Cell and Coverglass Analysis	Trays D9 & D3 (8° & 172° from ram)
NASA GSFC - S. Tiller	Si	4 arrays	S1001 - LDEF Heat Pipe Power System	Tray H1 (space end)
MBB - L. Preuss	Si	3	S1002 - Evaluation of Thermal Control Coatings/Solar Cells	Tray E3 (172° from ram)
TRW - J. Young	Si	12	A0054 - Space Plasma High Voltage Experiment	Trays B10 & D4 (22° & 158° from ram)

Advanced Photovoltaic Experiment (S0014)

This a pre-flight photo of the S0014 experiment. This experiment was designed to provide reference solar cell standards for laboratory measurements. This was to be accomplished by placing individual solar cells in orbit, measuring their current-voltage characteristics or short circuit current values while in orbit, and returning solar cells to the respective organizations for use as reference standards. On-orbit data acquisition took place once per day for the first 325 days of the LDEF mission. At day 326, the data acquisition batteries had discharged to the point that they were unable to further power the data recording system.



Preflight Photo of S0014

Advanced Photovoltaic Experiment Results To Date

The on-orbit data has been successfully read from the data acquisition system. Analysis of this data has been initiated. Post-flight I-V curves are being taken and comparison to pre-flight data has begun. Results to date include:

- The contamination film found on much of the cell surfaces has minimal effect on solar cell performance.
- Some discoloration in the RTV used to bond the cell wiring harness was observed.
- Degradation in I-V curves for individual cells was found to be mainly attributable to the severity of meteoroid or debris impact damage.

S0014 RESULTS TO DATE

Post flight I-V curves taken and comparison to pre-flight data underway

Analysis of on-orbit data has begun

Degradation in I-V curves proportional to severity of M&D damage

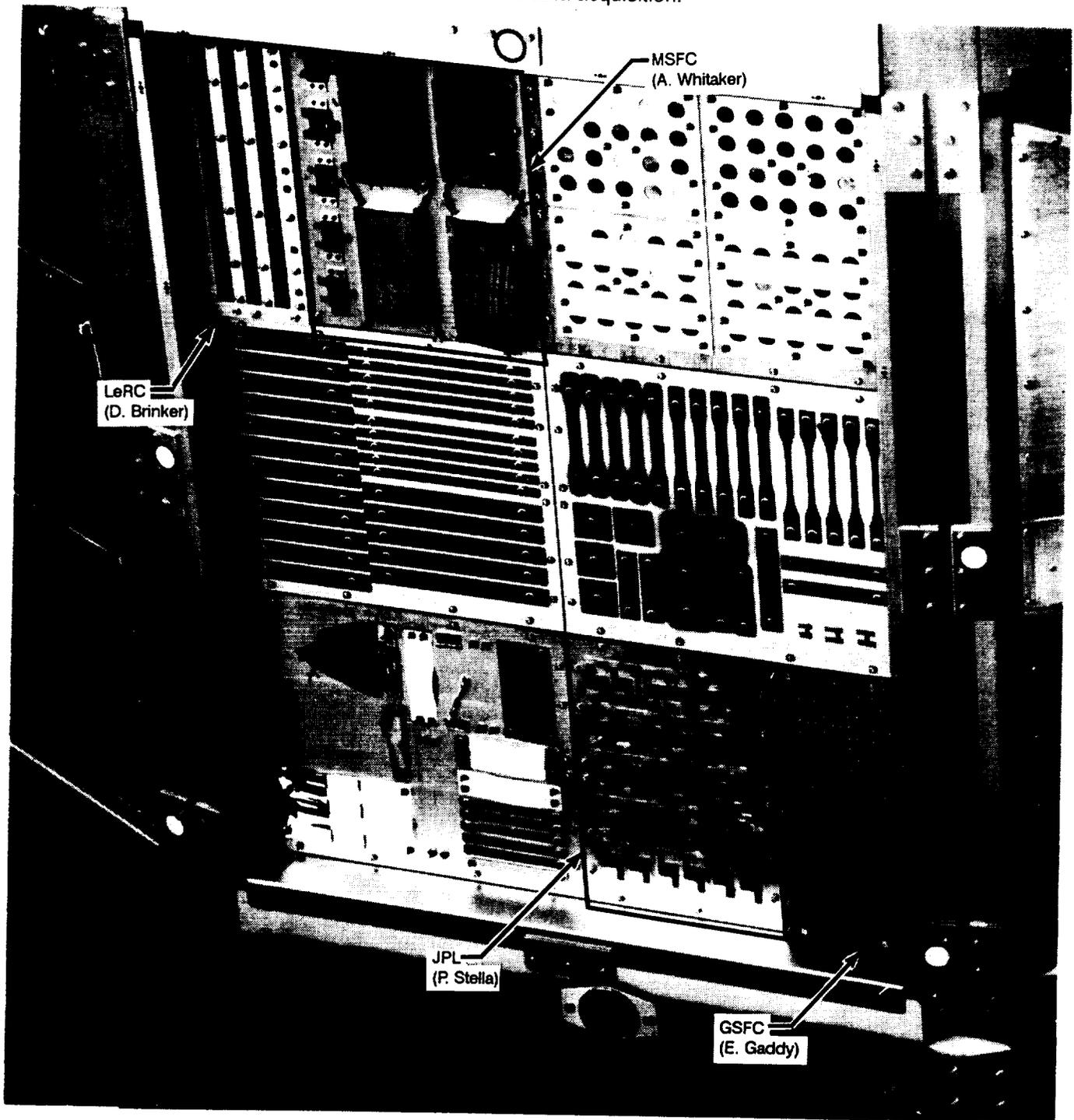
- **Cells with only coverglass damage showed minimal change**
- **Cells with damage to the structure show changes in fill factors**

Solar Array Passive LDEF Experiment (A0171)

This figure is an on-orbit photograph of Tray A8. The following four solar cell experiments were flown on this tray:

- MSFC experiment consisting of four solar cell modules and five solar cells
- JPL experiment consisting of 30 different combinations of cells/covers
- GSFC experiment consisting of testing solar cells, covers, encapsulants, and adhesives
- LeRC experiment consisted of solar cells with covers

This was a totally passive experiment with no on-orbit data acquisition.



On-Orbit photograph of Tray A8 which contained four different solar cell experiments.

A0171 Results to Date (MSFC portion)

Design of the four solar cell modules included the use of Kapton substrates. As a result of the longer than planned mission, the atomic oxygen caused erosion of the Kapton substrate resulted in two of the four modules becoming separated from the experiment prior to grappling and, therefore, not retrieved. The first of these two was lost prior to Shuttle rendezvous with LDEF, and the second one was still within close proximity during the grappling of LDEF. The third module was attached at one corner when LDEF was retrieved (as can be seen in the previous figure). This module (M3) was later found on the Shuttle cargo bay floor after LDEF was removed. This module was found to have five of the twelve cells containing cracks in either the solar cell or cell cover. The fourth module (M4) remained attached to the tray.

Solar cell and solar cell module maximum power (Pmp) output degradation ranged from 4.3% to 80% but over three-quarters of the individual cells tested had less than 10% degradation. There were 4 cells out of the 18 tested (including the twelve cells from M3) which had a Pmp degradation of greater than 20%. Three of these cells were from the M3 module and the fourth cell was flown without a coverglass. Discounting these four cells, the average cell Pmp degradation was 6.5%.

A0171 RESULTS TO DATE (MSFC portion of A0171)

- **Extended exposure caused loss of modules using Kapton substrate**
- **Solar modules performance degradations ranged between 4% and 80%**
 - **75% of the single cells exhibited < 10% degradation**
- **Exact degradation mechanisms yet to be determined**

A0171 Results to Date (JPL Portion)

This experiment studied the effects of exposure to the LEO environment on 30 different combinations of solar cells and coverglasses. The solar cell material for the 30 cells was Solarex Corporation 50-micron thick 2x2 cm silicon. Results to date include:

- The test plate and cells exhibited brownish-orange stains, which are residues of adhesives and encapsulates that had reacted to the LDEF and LEO environment.

- Large numbers of meteoroid and debris impacts are apparent ranging in size from 0.05 mm to 1.0 mm in diameter with > 157 total impacts over the 180 square inches of JPL's portion of the A0171 experiment.

- No impact damage was found to have caused any significant degradation to the solar cells. The degradation in cell performance for all samples was due to a loss of cell current due to darkening of the adhesive and/or coverglass due to exposure to UV, charged particles, and/or atomic oxygen.

- Short-circuit current loss ranged from 3% for the cerium doped microsheet coverglass cells to 22% for the Teflon encapsulated solar cells.

A0171 RESULTS TO DATE (JPL portion of A0171)

- **No significant degradation caused by M & D impacts**
- **Degradation caused by darkening of adhesive and/or coverglass due to exposure to AO, UV, and radiation**

LDEF Heat Pipe Power System Solar Arrays (S1001)

The LDEF Heat Pipe Power System Experiment included a self-contained direct-energy transfer power system which functioned properly during the entire mission lifetime. This power system was designed to provide power to the Low Temperature Heat Pipe Experiment and was located on the space end of LDEF. The power system included four solar array panels and one 18-cell, 12 amp-hr, nickel-cadmium battery. This figure is an on-orbit photograph of the four arrays.



On-Orbit Photo of S1001 Solar Arrays

S1001 Results to Date

A detailed visual inspection of the four arrays found that most cell damage could be attributed to the 99 meteoroid and debris impacts, of which 29 impacts caused coverglass cracks. Post-flight IV analysis made five months after LDEF retrieval indicated that the solar panel's current and voltage performance had degraded an average of 1.5% and 3.3% respectively. The degradation was concluded to be caused by darkening of coverglass adhesive and impact damage. The extent of damage due to any one of the mechanisms is currently unknown.

S1001 RESULTS TO DATE

Visual Inspection

- **99 M&D impacts**
- **22 impacts caused coverglass cracks**
- **Adhesive migration**

Electrical Characterization

- **Average of four modules**
 - **Current degraded 1.5%**
 - **Voltage degraded 3.3%**
- **Control module**
 - **Current degraded 0.3%**
 - **Voltage degraded 0.6%**
- **Flight degradation due to darkening of coverglass adhesive and M&D damage**

Advanced Solar Cell and Coverglass Analysis (M0003-4) Results to Date

This experiment consisted of 63 coverglass samples and 12 solar cell strings (5 cell/string). Of the 63 coverglasses, 16 were on the leading edge, 16 on the trailing edge, 16 on the backside of a tray protected from direct exposure to the LEO environment, and 15 were used as control samples and not flown. 5 of the cell strings were on the leading edge, 5 on the trailing edge and 2 were used as control strings.

The surface contamination found on all specimens did not interfere to a significant degree with the optical characteristics, but the contamination film does increase the absorption by moving the short wavelength transmission of the top surface to longer wavelengths.

Visual comparisons of cell strings indicated that the metallization process will have a large effect on the lifetime of arrays in LEO orbit. Metal migration and contamination between the coverglass and cell are two of the main concerns. Electrical characterization of these cell strings has not yet been initiated.

M0003-4 RESULTS TO DATE

Coverglass

- **Optical properties determined. No significant changes. Trailing edge specimens "dirtier" than leading edge specimens.**

Solar Cells

- **Oxidation of silver; contamination; discoloration on cell contacts and interconnects.**
- **Electrical characterization not yet begun.**

Solar Cell Conclusions

There are four LEO environments, operating individually and/or synergistically, that cause performance loss in solar cells:

- Meteoroid and space debris
- Atomic oxygen
- Ultraviolet radiation
- Charged particle radiation

In addition, the effects of contamination caused by outgassing of materials used on the specific spacecraft play a role in decreasing the light being transmitted through the coverglass and adhesive to the solar cell.

From the results presented on the solar cells aboard LDEF, the most extensive degradation of the solar cells came from impacts and the resulting cratering. The extent of the damage to the solar cells was largely dependent upon the size and energy of the meteoroids or space debris.

The other cause of degradation was reduced light reaching the solar cell. This was caused by contamination, UV degradation of coverglass adhesive, and/or atomic oxygen/UV degradation of antireflection coatings.

For additional information, the reader is referred to either the individual papers presented at the First LDEF Post-Retrieval Symposium or the Systems SIG report dated February, 1992.

CONCLUSIONS, SOLAR CELLS

- **Approx. 340 Si & GaAs solar cells flown on LDEF**
- **Over half were actively monitored on-orbit**
- **Most degradation of cells caused by M&D impacts**
 - **Performance loss dependent on size and energy of impacts**
- **Minor degradation caused by decreased amount of light reaching cell**
 - **Contamination**
 - **UV degradation of coverglass adhesive**
 - **Atomic oxygen/UV degradation of antireflection coatings**
- **To date, radiation effects not discernible from other degradation factors**